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UTILIZING SPICE SIMULATION TO ADVANCE CIRCUIT DESIGN PROFICIENCY AMONG ELECTRICAL ENGINEERING STUDENTS IN CROSS RIVER STATE, NIGERIA

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Abstract
This study investigates the efficacy of SPICE (Simulation Program with Integrated Circuit Emphasis) simulation in enhancing circuit design proficiency among electrical engineering students in Cross River State, Nigeria. With the increasing complexity of modern electronics, proficiency in circuit design is critical for engineering graduates. However, traditional teaching methods often lack practical, hands-on simulation tools like SPICE, which can bridge theoretical knowledge and real-world application. Using a primary data collection method, this research involved 120 students from two institutions, the University of Calabar and the Cross River University of Technology, divided into experimental (SPICE-integrated) and control (traditional) groups. Pre- and post-intervention assessments measured circuit design skills, focusing on accuracy, speed, and problem-solving ability. Results revealed that the experimental group exhibited a statistically significant improvement ($p < 0.05$), with a mean score increase of 15.6 points compared to 4.2 in the control group. Qualitative feedback highlighted SPICE's role in enhancing understanding of circuit behavior and reducing design errors. The study aligns with global trends in engineering education, emphasizing simulation tools' transformative potential. Challenges such as limited computer access and software familiarity were noted, suggesting the need for infrastructural investment and training. This research contributes to the discourse on technology-enhanced learning in developing contexts, recommending the integration of SPICE into electrical engineering curricula in Cross River State to prepare students for industry demands. Future studies should explore long-term impacts and scalability across Nigeria.

Keywords: SPICE simulation, circuit design, electrical engineering, engineering education, technology-enhanced learning.

Introduction
Traditional pedagogical approaches, reliant on manual calculations and constrained laboratory resources, often fail to equip students with the hands-on skills required for modern circuit design (Odey & Okoi, 2023). This disconnect is evident in graduates' struggles to meet industry expectations, such as designing reliable and efficient electronic systems (Adebayo, 2022). In Cross River State, where institutions like the University of Calabar (UNICAL) and Cross River University of Technology (CRUTECH) serve as key training grounds, the lack of simulation-based learning exacerbates these challenges. As electronic systems grow increasingly complex, proficiency in tools like SPICE becomes essential, yet its adoption remains limited in Nigeria's semi-urban and rural educational contexts (Akanbi, 2021).

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The integration of simulation tools like SPICE (Simulation Program with Integrated Circuit Emphasis) into electrical engineering education has sparked extensive scholarly debate since its development in the 1970s. Early proponents, such as Nagel and Pederson (1973), argued that SPICE revolutionized circuit design by enabling precise modeling of semiconductor behavior, a view echoed by Roberts and Sedra (1997) who emphasized its role in transitioning students from theoretical calculations to practical application. This perspective posits that simulation tools enhance conceptual understanding by allowing iterative experimentation, a claim supported by empirical evidence from Smith and Jones (2020), who found a 30% improvement in nonlinear circuit analysis among U.S. students using SPICE. However, critics like Horowitz and Hill (1989) cautioned against over-reliance on simulation, asserting that it could undermine foundational skills in manual analysis, potentially producing engineers overly dependent on software.

The scholarly debate underscores a critical tension: while simulation tools hold transformative potential, their success hinges on contextual adaptation. Despite its growing engineering programs and unique socio-economic landscape, no comprehensive study has evaluated SPICE’s impact in Cross River State. This research introduces a novel contribution by examining SPICE’s efficacy in a semi-urban Nigerian setting, offering empirical evidence to inform educational policy. Unlike prior studies focused on urban centers (e.g., Lagos or Edo), this work targets a less-studied region, blending primary data with a localized lens to bridge the theory-practice gap.

The new thing that the study tends to achieve lies in its localized, primary-data-driven approach to assessing SPICE’s impact on circuit design proficiency, an area yet to be comprehensively explored by other scholars in Cross River State. Unlike prior studies that rely on secondary data or broad surveys (Akanbi, 2021; Okafor & Musa, 2023), this research employs a quasi-experimental design with pre- and post-intervention assessments, coupled with qualitative student feedback, to offer a granular understanding of SPICE’s pedagogical value. Furthermore, it bridges global trends with local realities by testing a widely acclaimed tool in a developing context, contributing to the global conversation on technology-enhanced learning while addressing Nigeria-specific challenges like software accessibility and instructor training. This dual focus on efficacy and feasibility sets it apart from existing works, providing a blueprint for integrating simulation tools into under-resourced engineering programs, a contribution with potential implications for educational policy and practice across Sub-Saharan Africa.

ELT provides a lens to evaluate SPICE simulation’s impact on circuit design proficiency among electrical engineering students in Cross River State, Nigeria. The four-stage cycle directly applies: students engage in concrete experience by simulating circuits using SPICE, observing real-time outcomes such as voltage drops or signal distortions. Through reflective observation, they analyze simulation results, identifying discrepancies between expected and actual performance. This leads to abstract conceptualization, where students connect simulation insights to theoretical principles like Ohm’s Law or Kirchhoff’s Laws, deepening their understanding of circuit behavior. Finally, active experimentation occurs as they modify circuit parameters, e.g., resistor values or capacitor sizes, to optimize designs, iterating until desired outcomes are achieved. This cyclical process mirrors SPICE's hands-on, iterative nature, fostering skills in accuracy, speed, and problem-solving. By facilitating this experiential loop, SPICE aligns with ELT’s assumption that learning emerges from active engagement, making it an ideal tool to bridge theoretical knowledge and practical application in a resource-constrained educational context.

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Method

This study adopted a quasi-experimental design with a pre-test/post-test framework to evaluate the effectiveness of SPICE simulation in enhancing circuit design proficiency. The quasi-experimental approach was chosen for its suitability for educational settings where random assignment is impractical (Creswell & Creswell, 2018). Two groups were established: an experimental group exposed to SPICE-integrated instruction and a control group taught using traditional methods. The design allowed for comparison of skill improvement between groups while controlling for baseline proficiency through pre-testing. The target population comprised third-year electrical engineering students from tertiary institutions in Cross River State, Nigeria, selected for their foundational knowledge of circuit theory and readiness for advanced design skills. Two institutions, the University of Calabar (UNICAL) and Cross River University of Technology (CRUTECH), were purposively selected due to their established engineering programs and accessibility. From a total population of approximately 300 third-year students across both institutions, a sample of 120 students was drawn using purposive sampling to ensure participants had comparable academic exposure. Each institution contributed 60 students, equally divided into experimental (30) and control (30) groups. This sample size was determined using G*Power software, ensuring statistical power of 0.80 at a 0.05 significance level for detecting a medium effect size (Cohen, 1988).

Table 1

The demographic details of the participants in the study

Demographic Characteristic	Details
Population	Third-year electrical engineering students from tertiary institutions in Cross River State, Nigeria
Total Population Size	Approximately 300 third-year students across the two institutions
Sample Size	120 students
Institutions Involved	University of Calabar (UNICAL) and Cross River University of Technology (CRUTECH)
Sample Distribution per Institution	60 students from UNICAL, 60 students from CRUTECH
Group Division	Experimental Group: 60 students (30 from UNICAL, 30 from CRUTECH); Control Group: 60 students (30 from UNICAL, 30 from CRUTECH)

Data Collection Instruments

Primary data were collected using multiple instruments to provide a comprehensive assessment of circuit design proficiency and student perceptions:

1. Pre-Test and Post-Test:

   A standardized circuit design task was developed, consisting of 20 questions divided into three domains: accuracy (e.g., correct component selection), speed (time to complete designs), and problem-solving (e.g., troubleshooting faulty circuits). Each question was

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scored on a rubric (max score: 50), validated by two electrical engineering lecturers for content relevance.

The pre-test established baseline proficiency, while the post-test, identical in structure, measured improvement post-intervention.

2. SPICE Simulation Performance Log:

For the experimental group, a log tracked the number of simulations completed, error rates, and design iterations during the intervention, providing quantitative data on engagement with SPICE.

3. Questionnaire:

A 10-item questionnaire using a 5-point Likert scale (1 = Strongly Disagree, 5 = Strongly Agree) assessed students' perceptions of SPICE's utility, ease of use, and impact on learning. Items included statements like "SPICE improved my understanding of circuit behavior" and "I found SPICE easy to navigate." The questionnaire was pilot-tested with 15 students outside the sample to ensure clarity and reliability (Cronbach's alpha = 0.87).

Intervention Procedure

The intervention spanned six weeks, conducted between February and March 2025, aligning with the academic calendar. The experimental group participated in a structured SPICE training program using LTspice, a free and widely accessible version of SPICE:

Week 1: Introduction to LTspice, including installation, interface navigation, and basic circuit entry (e.g., resistors, capacitors, voltage sources).

Week 2-3: Transient analysis and DC sweep simulations, focusing on time-domain behavior and parameter variation.

Week 4-5: Advanced topics, including AC analysis, frequency response, and optimization of amplifier circuits.

Week 6: Capstone project requiring students to design and simulate a functional circuit (e.g., a low-pass filter), followed by the post-test.

Sessions were held twice weekly (2 hours each) in computer labs, facilitated by trained instructors. The control group followed the standard curriculum, relying on lectures, manual calculations, and limited physical prototyping, with no exposure to SPICE. Both groups received identical theoretical content on circuit design principles to ensure comparability.

Data Analysis

Data were analyzed using both quantitative and qualitative methods:

Quantitative Analysis:

Paired t-tests compared pre- and post-test scores within each group to assess individual improvement.

An independent t-test evaluated differences in post-test scores between the experimental and control groups, testing the hypothesis that SPICE enhances proficiency.

Descriptive statistics (means, standard deviations) summarized performance logs and questionnaire responses.

Statistical analyses were conducted using SPSS version 26, with a significance level of $p < 0.05$.

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Qualitative Analysis:

Open-ended questionnaire responses were thematically analyzed using NVivo software to identify recurring themes (e.g., perceived benefits, challenges). Coding followed Braun and Clarke's (2006) six-phase approach: familiarization, coding, theme generation, review, definition, and reporting.

Validity and Reliability

To ensure validity, the pre- and post-test instruments were aligned with course learning outcomes and reviewed by subject matter experts. A pilot test with 20 students confirmed item clarity and consistency (inter-rater reliability = 0.91). SPICE training materials were standardized across facilitators to minimize instructional bias. Reliability of the questionnaire was established through Cronbach's alpha, while triangulation of test scores, performance logs, and survey data enhanced overall credibility.

Results

The study yielded comprehensive insights into the impact of SPICE simulation on circuit design proficiency among electrical engineering students in Cross River State, Nigeria. Data were collected from 120 participants (60 experimental, 60 control) across UNICAL and CRUTECH, with results analyzed quantitatively and qualitatively.

Quantitative Results

Pre- and post-test scores were evaluated to assess improvements in accuracy, speed, and problem-solving ability. Table 2 summarizes the overall performance:

Table 2

Pre- and Post-Test Scores Across Groups

Group	Pre-Test Mean (SD)	Post-Test Mean (SD)	Mean Difference	t-value	p-value
Experimental	25.4 (3.2)	41.0 (2.8)	15.6	8.45	<0.001
Control	26.1 (3.5)	30.3 (3.1)	4.2	2.13	0.042

Note. The experimental group demonstrated a significant improvement ($t = 8.45$, $p < 0.001$), with a mean score increase of 15.6 points, compared to the control group's modest gain of 4.2 points ($t = 2.13$, $p = 0.042$). An independent t-test between post-test scores confirmed SPICE's superior impact ($t = 7.92$, $p < 0.001$). To explore skill-specific outcomes, scores were disaggregated into accuracy, speed, and problem-solving components (see Table 3):

Table 3

Skill-Specific Post-Test Scores (Max Score: 50)

Skill Component	Experimental Mean (SD)	Control Mean (SD)	t-value	p-value
Accuracy	14.8 (1.2)	10.5 (1.5)	6.23	<0.001
Speed (minutes)	12.6 (1.0)	9.8 (1.3)	5.87	<0.001
Problem-Solving	13.6 (1.1)	10.0 (1.4)	5.45	<0.001

Note. Accuracy improved most markedly in the experimental group (14.8 vs. 10.5), reflecting SPICE's ability to visualize circuit behavior, aligning with Smith and Jones (2020). Speed gains (12.6 vs. 9.8) suggest enhanced efficiency, while problem-solving scores (13.6 vs. 10.0) indicate better analytical skills, consistent with Lee et al. (2022).

Institutional differences were also examined (Table 4):

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Table 4

Post-Test Scores by Institution (Experimental Group Only)

Institution	Mean (SD)	Sample Size	t-value (vs. Control)	p-value
UNICAL	42.3 (2.5)	30	7.12	<0.001
CRUTECH	39.7 (2.9)	30	6.89	<0.001

UNICAL students slightly outperformed CRUTECH counterparts ($t = 2.34$, $p = 0.022$), possibly due to better baseline resources (Odey & Okoi, 2023).

Qualitative Results

The post-intervention questionnaire ($n = 60$, experimental group) revealed strong positive perceptions. Table 5 summarizes key themes:

Table 5

Student Perceptions of SPICE (5-Point Likert Scale, 1 = Disagree, 5 = Agree)

Statement	Mean (SD)	% Agree (4-5)
SPICE improved circuit understanding	4.3 (0.6)	78%
SPICE reduced design errors	4.1 (0.7)	65%
SPICE was easy to learn	3.6 (0.9)	48%
Access to computers was adequate	3.2 (1.0)	33%

Students valued SPICE's role in clarifying complex concepts (78% agreement), echoing Egbunike et al. (2024). Error reduction (65%) was attributed to real-time feedback. However, software complexity (48% found it easy) and limited computer access (33% adequacy) emerged as barriers, consistent with Okafor and Musa (2023). Open-ended responses highlighted specific benefits, such as "SPICE helped me see why my circuit failed" (UNICAL student), and challenges, like "I needed more time to master it" (CRUTECH student).

Statistical Reliability

Cronbach's alpha for the questionnaire was 0.82, indicating high internal consistency. Test-retest reliability for the design task was 0.89, ensuring measurement stability.

Discussion

The results affirm SPICE simulation's transformative potential in enhancing circuit design proficiency among electrical engineering students in Cross River State. The experimental group's significant gains (15.6 points vs. 4.2, $p < 0.001$) align with global findings (Smith & Jones, 2020), where simulation tools improved design accuracy by 30%. Skill-specific improvements accuracy (14.8 vs. 10.5), speed (12.6 vs. 9.8), and problem-solving (13.6 vs. 10.0) reflect SPICE's capacity to provide real-time insights into circuit dynamics, supporting Kolb's experiential learning theory (1984). UNICAL's slight edge over CRUTECH (42.3 vs. 39.7) suggests resource disparities influence outcomes, corroborating Odey and Okoi (2023).

Qualitatively, students' appreciation of SPICE's clarity (78%) and error reduction (65%) mirrors Egbunike et al. (2024), who noted similar benefits in Edo State. However, challenges like software complexity (48% ease) and inadequate computer access (33%) echo Okafor and Musa (2023),

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highlighting infrastructural deficits in Nigerian tertiary institutions. These barriers underscore the need for targeted interventions to maximize SPICE's impact.

The study's implications extend beyond Cross River State, contributing to the discourse on technology-enhanced learning in developing contexts. SPICE bridges the theory-practice gap, preparing students for industry demands (Cohen, 2021). Yet, its success hinges on addressing resource constraints. Compared to Lee et al. (2022), where Asian students thrived with robust infrastructure, Nigeria's context demands adaptive strategies. Limitations include the short intervention duration and sample size, suggesting future research explore scalability and longitudinal effects. Overall, SPICE emerges as a vital tool, warranting curriculum integration and institutional support.

Conclusion

This study demonstrates that SPICE simulation significantly enhances circuit design proficiency among electrical engineering students in Cross River State, Nigeria, offering a transformative approach to bridge the gap between theoretical knowledge and practical application. The experimental group's marked improvement in accuracy, speed, and problem-solving ability, evidenced by a 15.6-point mean score increase compared to the control group's 4.2, underscores SPICE's potential as a pedagogical tool ($t = 8.45$, $p < 0.001$). These findings align with global trends where simulation-based learning has revolutionized engineering education (Smith & Jones, 2020; Lee et al., 2022), yet they are particularly significant in the Nigerian context, where resource constraints often limit hands-on experience (Okafor & Musa, 2023). The qualitative data further illuminate SPICE's value, with students reporting enhanced comprehension of circuit dynamics and reduced design errors, reinforcing the constructivist and experiential learning theories that underpin this research (Piaget, 1970; Kolb, 1984).

Beyond skill enhancement, SPICE fosters critical thinking and adaptability attributes essential for addressing real-world engineering challenges, such as designing sustainable energy systems or robust communication networks, which are pressing needs in Nigeria's developing economy (Adebayo, 2022). However, the study also highlights implementation challenges, including limited computer access, initial software complexity, and the need for instructor training. While not insurmountable, these barriers reflect broader systemic issues in Nigerian tertiary education, such as underfunding and infrastructural deficits (Odey & Okoi, 2023). Overcoming them requires a concerted effort from educational stakeholders.

In conclusion, integrating SPICE into the electrical engineering curriculum in Cross River State elevates student proficiency and positions graduates to meet industry demands, contributing to technological advancement in the region. This research lays a foundation for broader adoption across Nigeria, suggesting that simulation tools can democratize access to quality engineering education in resource-constrained settings. Future investigations should explore long-term skills retention and scalability to other disciplines, ensuring that the benefits observed here endure and expand.

Recommendations

Based on the study's findings, the following recommendations are proposed to maximize SPICE's impact on electrical engineering education in Cross River State and beyond:

1. The University of Calabar (UNICAL) and Cross River University of Technology (CRUTECH) should formally incorporate SPICE into their electrical engineering curricula, embedding it within core courses like Circuit Theory and Electronics Design. This aligns with

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recommendations from Egbunike et al. (2024), who advocate for simulation tools to complement traditional methods. A phased approach starting with introductory workshops and progressing to advanced applications could ease the transition for students and faculty.

2. Institutions must prioritize funding for computer laboratories equipped with sufficient hardware and SPICE software licenses (e.g., LTspice or Multisim). The study identified limited computer access as a barrier (33% of respondents), consistent with Okafor and Musa (2023), who note that infrastructural deficits hinder technology adoption in Nigeria. Government and private sector partnerships could subsidize costs, ensuring equitable access across urban and rural campuses.

3. Comprehensive training for lecturers is essential to build confidence in using SPICE and integrating it into teaching. Workshops led by simulation experts, potentially in collaboration with international bodies like IEEE, could address the initial software complexity reported by 42% of students. Cohen (2021) emphasizes that instructor proficiency is critical for successful technology-enhanced learning, a lesson applicable here.

4. Establish peer mentoring and technical support units to assist students in mastering SPICE, particularly those with limited prior exposure to simulation tools. This could include online tutorials and troubleshooting guides, reducing the learning curve and enhancing engagement, as suggested by Lee et al. (2022).

5. Educational policymakers in Cross River State and Nigeria's National Universities Commission (NUC) should incentivize simulation-based learning through grants and curriculum reviews. This aligns with global best practices (Smith & Jones, 2020) and could position Nigeria as a leader in African engineering education innovation.

6. Future studies should track the long-term impact of SPICE on graduates' employability and innovation capacity, comparing outcomes with other Nigerian regions or African countries. This would build on Akanbi's (2021) call for context-specific research, providing a robust evidence base for scaling interventions.

7. Partner with local electronics firms to align SPICE training with industry needs, such as circuit optimization for renewable energy systems a priority in Nigeria's development agenda (Adebayo, 2022). Such collaborations could offer students internships, reinforcing practical skills.

These recommendations, if implemented, could transform electrical engineering education in Cross River State, fostering a generation of proficient, industry-ready engineers. Addressing the identified challenges through strategic investment and collaboration will ensure that SPICE's benefits are fully realized, contributing to both educational excellence and socioeconomic progress.

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